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# The Origin of Groundwater Discharge at Burney Falls, Shasta Co.,California

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## Summary

Stable isotope measurements of surface water and groundwater from the Burney Basin and northern Hat Creek Basin indicate that spring discharge at Burney Falls is a mixture of water derived from both basins. Relative mixing proportions depend on the assumed isotopic composition of each end-member, but plausible mixing models suggest that approximately 40 to 60% of the spring water originates from the Burney Basin. The isotope data also indicate that Burney Creek cannot be the dominant source of Burney Falls Springs.

## Purpose of Report

The proposed development of a new power plant (Three Mountain Project) in the Burney Basin area of northeastern California provided the impetus for this brief report on the origin of groundwater discharge at Burney Falls Springs. The proposed project is situated ~13 km up-gradient of McArthur-Burney Falls Memorial State Park, where groundwater emanates from a group of large springs at a rate of approximately 4.2 to 6.4 $m^3s^{-1}$ (150-225 $ft^3s^{-1}$; data from Waring, 1915; Meinzer, 1927). This report discusses stable isotope data for water samples that were gathered from this region by the author in the mid-1990's. The intent is to provide impartial scientific evidence that may assist in the environmental risk assessment process.

## Hydrologic Setting of Burney Falls

Burney Falls Springs are one of several voluminous springs that discharge from fractured volcanic aquifers in northeastern California. Rose et al. (1996) showed that these springs are hydrologically linked to high elevation source areas that receive large amounts of precipitation, especially during the winter months. These source areas are often tens of kilometers distant from the springs. Snowmelt and rainfall infiltrates fractured volcanic rocks in the source areas and moves down gradient along permeable layers to where the water resurfaces at springs. The largest springs typically occur at the terminus of large lava flows, or where erosion has cut into the volcanic layers to expose transmissive units. Burney Falls Springs generally fall into the latter category, although geologic evidence suggests that spring discharge is further controlled by the presence of low permeability lake sediments underlying the younger basalt aquifers in this area (Aune, 1964; MacDonald, 1966).

## Isotopic Fingerprinting of Natural Waters

The stable (non-radioactive) isotopes of hydrogen ($^1H$ and $^2H$) and oxygen ($^{18}O$ and $^{16}O$) are excellent water tracers because they are an essential component of the water molecule. The $^2H/^1H$ (or D/H) and $^{18}O/^{16}O$ ratios in precipitation vary according to elevation and distance from the ocean. On a local scale, an altitude difference of 250 m produces a clear and measurable change in the D/H and $^{18}O/^{16}O$ ratios of precipitation. These isotope ratios are preserved once the precipitation infiltrates to the saturated groundwater zone. It is therefore possible to use D/H and $^{18}O/^{16}O$ ratios to determine the source areas for groundwater, and to discriminate the presence of multiple water sources.

Oxygen and hydrogen isotope measurements are reported as δ-values, representing the permil (‰, or parts per thousand) difference in the isotope ratio of a sample relative to a reference standard:

$$\delta = 1000\left[\frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}}\right] \qquad (1)$$

where $R$ refers to the appropriate isotope ratio (D/H or $^{18}O/^{16}O$). The internationally accepted reference standard for $\delta D$ and $\delta^{18}O$ analyses of waters is Standard Mean Ocean Water (SMOW). Reported values have an analytical precision of ±0.1‰ for $\delta^{18}O$ and ±1‰ for $\delta D$.

## Oxygen and Hydrogen Isotope Variations in the Burney Basin

The locations of water samples from the Burney Basin and adjacent parts of the Hat Creek Basin are shown on a map in Figure 1. For the purpose of this report, the Burney Basin is defined as the region that lies approximately within the Burney Creek drainage area. The results of $\delta D$ and $\delta^{18}O$ analyses of these waters are reported in Table 1, and are plotted in Figure 2. Most of the data cluster along the line $\delta D = 8\delta^{18}O + 10$, known as the Global Meteoric Water Line (GMWL; Figure 2). In general, precipitation samples collected anywhere on earth plot very close to this line (Craig, 1961). The close relationship of the Burney and Hat Creek Basin waters to the GMWL indicates these waters originated from precipitation.

Groundwater samples were collected at Burney Falls Springs on two separate occasions, in May 1994 and February 1995. In each case, the samples were taken where groundwater emerges from the rock near the base of the falls. The $\delta^{18}O$ values of these samples (-13.0 and -13.1‰) differ appreciably from samples collected from Burney Creek during the same two sampling trips ($\delta^{18}O$ = -12.2 and -11.9‰). The difference in the isotopic composition of Burney Falls Springs and Burney Creek implies the creek is not the principal source of the springs, as had been previously suggested (e.g. Meinzer, 1927).

Two additional groundwater samples were collected in close proximity to Burney Falls. A pumped sample was collected from a production well on the property of the Hat Creek Construction Co. (Rimrock Well) located ~3 km southeast of Burney Falls. This sample has a $\delta^{18}O$ value of -13.3‰. Groundwater was also collected from Salmon Springs, a group of large springs (~1.4 $m^3s^{-1}$ or 50 $ft^3s^{-1}$) located about 4 km due east of Burney Falls, on south side of the Pit River gorge. Salmon Springs have a $\delta^{18}O$ value of -13.6‰, and closely resemble groundwater from the northern Hat Creek Basin, which ranges in $\delta^{18}O$ from -13.6 to -14.2‰. The fact that groundwater $\delta^{18}O$ values become more negative to the east of Burney Falls implies that groundwater flow is increasingly derived from the Hat Creek Basin in this direction.

Note that with the exception of Rimrock Well and Salmon Springs, all other water samples from Burney Basin have $\delta^{18}O$ and $\delta D$ values *less* negative than Burney Falls (Figure 2). Mixing relationships are linear in Figure 2, and the intermediate position of Burney Falls between the Burney Basin and Hat Creek Basin samples implies it is a mixture of water from these two basins. The relative proportion of each component can be approximately determined from the following two-component mixing equation:

$$\delta_{BF} = \delta_1 X_1 + \delta_2 X_2 \qquad (2)$$

where $\delta_{BF}$ is the $\delta^{18}O$ (or $\delta D$) value of Burney Falls, $\delta_1$ and $\delta_2$ are the corresponding $\delta$-values for the Burney Basin and Hat Creek Basin groundwaters, and $X_1$ and $X_2$ is the fractional amount of each mixing component, where $X_1 + X_2 = 1$. Given that $X_2 = 1 - X_1$, equation (2) can be rewritten in the following form:

$$\delta_{BF} = \delta_1 X_1 + \delta_2(1 - X_1) \qquad (3)$$

Obviously the relative proportions of the two components will depend on the assumed end-member $\delta$-values. Groundwater from Burney Spring (near Burney Mtn.) and Burney Municipal Well #6 both have $\delta^{18}O$ values of -12.7‰, and are probably derived from high elevation recharge on Burney Mountain (elevation 2397 m). If we assume that this value approximately represents the Burney Basin mixing component, and assume that Salmon Springs represents the Hat Creek Basin mixing component, we obtain the following relationship from equation (3):

$$-13.05 = (-12.7)X_1 + (-13.6)(1 - X_1)$$

where -13.05 is the average of the two $\delta^{18}O$ measurements at Burney Falls Springs. Solving this equation yields $X_1 = 0.61$, implying that 61% of the water is derived from Burney Basin (and hence 39% is from Hat Creek Basin). Varying the assumed $\delta^{18}O$ values of the two mixing components yields somewhat different mixing proportions. The same equation can also be applied using $\delta D$ values instead of $\delta^{18}O$ values. For example, assuming the same mixing end-members as above, but using $\delta D$ values, we obtain the following expression:

$$-94 = (-89.5)X_1 + (-99)(1 - X_1)$$

which yields $X_1 = 0.53$, or 53% of the Burney Falls Springs groundwater derived from the Burney Basin. These mixing relationships are intended to be illustrative rather than exact. For instance, if Burney Creek were used as a mixing end-member instead of Burney Mountain groundwater, then the relative proportion of Burney Basin water would decrease to less than 40%.

In summary, the available isotopic evidence strongly suggests a mixed origin for the groundwater at Burney Falls. Given the variation in isotope values of water samples collected near Burney Falls (i.e. Rimrock Well, Salmon Springs, Burney Creek), it is likely that mixing occurs within a few kilometers of the spring discharge area. To determine whether the relative mixing proportions vary at different times during the year, it would be necessary to implement a longer-term monitoring program.

## Acknowledgement

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Table 1. Sample locations and isotopic data.

| Sample Name | Sample location (Township, Range, Section) | Date | $\delta^{18}O$ (‰ SMOW) | $\delta D$ (‰ SMOW) |
|---|---|---|---|---|
| *Burney Basin* | | | | |
| Salmon Springs | sec. 2, T36N, R3E | 19-Jun-95 | -13.6 | -99 |
| Burney Falls - (5/94) † | sec. 5, T36N, R3E | 15-May-94 | -13.0 | -93 |
| Burney Falls - (2/95) | sec. 5, T36N, R3E | 14-Feb-95 | -13.1 | -95 |
| Burney Creek (above Burney Falls) | sec. 4, T36N, R3E | 14-Feb-95 | -11.9 | -83 |
| Burney Creek (Tamarack Rd, Burney) | sec. 24, T35N, R2E | 14-May-94 | -12.2 | -87 |
| Rimrock Well | sec. 10, T36N, R3E | 3-Sep-95 | -13.3 | -96 |
| Burney Municipal Well #6 | sec. 20, T35N, R3E | 17-Feb-94 | -12.7 | -90 |
| Dry Lake Spring * | sec. 13, T34N, R2E | 14-May-94 | -10.5 | -79 |
| Burney Spring (N. of Burney Mtn) | sec. 27, T34N, R3E | 14-May-94 | -12.7 | -89 |
| Garden Meadows Spring | sec. 12, T33N, R2E | 20-May-94 | -12.2 | -88 |
| Clover Creek Spring | sec. 7, T33N, R2E | 20-May-94 | -12.4 | -85 |
| Stacher Butte Spring | sec. 19, T33N, R2E | 20-May-94 | -12.1 | -83 |
| *Northern Hat Creek Basin (nr. Cassel)* | | | | |
| Crystal Lake Springs | sec. 32, T36N, R4E | 17-Feb-94 | -14.0 | -102 |
| Dave Bower's Well, Cassel | sec. 5, T35N, R4E | 17-Feb-94 | -13.8 | -98 |
| Cassel Park Mutual Water Well #1 | sec. 6, T35N, R4E | 17-Feb-94 | -13.6 | -99 |
| Rock Spring | sec. 4, T35N, R4E | 17-Feb-94 | -14.2 | -104 |
| Rising River Springs | sec 16, T35N, R4E | 14-Feb-95 | -13.9 | -100 |

† The $\delta D$ value for Burney Falls (5/94) differs from the value reported in Rose et al. (1996) by 2‰; the value reported here is correct for this sample.

* The $\delta^{18}O$ and $\delta D$ values for Dry Lake Spring reflect natural evaporation processes.

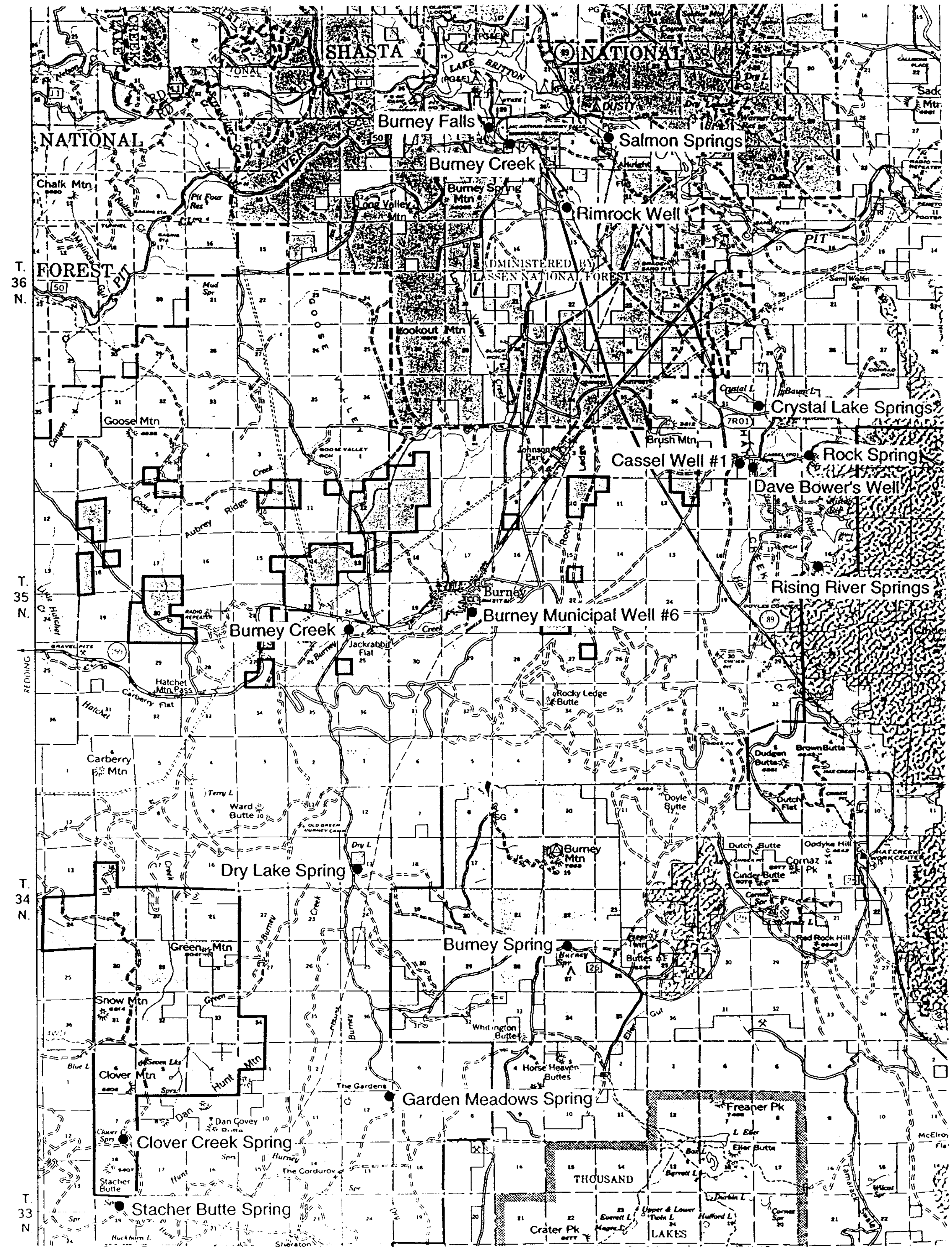


**Figure 1.** Map of the Burney Basin region showing locations of water samples discussed in this report. Base map is the Lassen National Forest Sheet, U.S. Forest Service (1987).

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

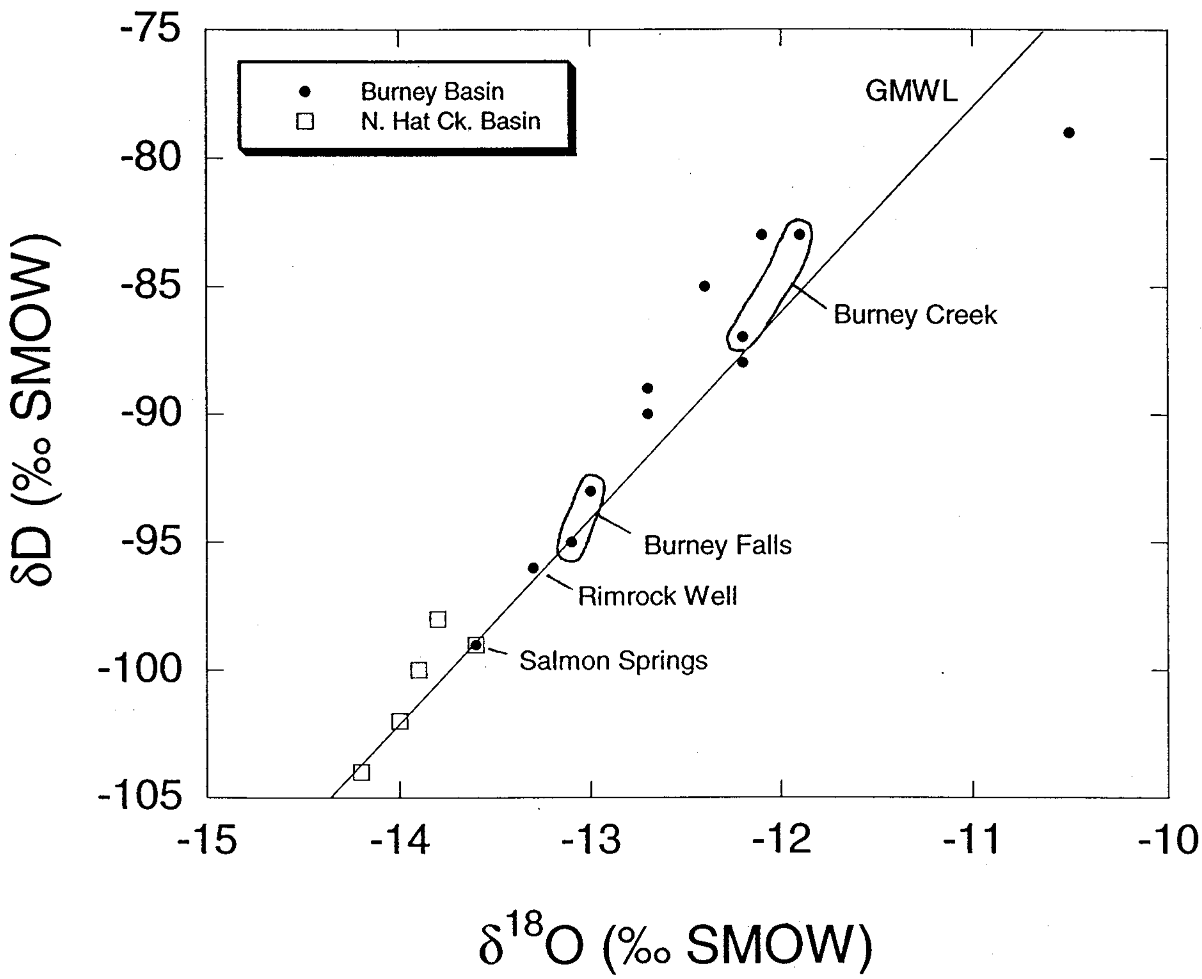


**Figure 2.** Plot of δD versus $\delta^{18}O$ values for water samples from the Burney Basin (solid circles) and northern Hat Creek Basin (open squares). Most of the samples plot close to the global meteoric water line (GMWL), indicating an origin from local precipitation.